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THE ASSOCIATION OF ACCIDENT SEVERITY AND FREQUENCY WITH VEHICLE AGE*

A Study in Three Michigan Counties for the Period 1 January to 30 September, 1966

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INTRODUCTION

"DETERIORATION OF a vehicle with time is inescapable, whether from normal wear, abuse, defective construction, improper maintenance, poor quality of original or repair parts, inadequate skill of mechanics or other factors. With the deterioration of such components as brakes, steering systems, and tires, the chances of the vehicle becoming involved in a crash increase." This assertion was made by the Secretary of Transportation in his July 1968 report to the Congress (1968) and it reflects the intuitive approach taken by some highway safety advocates. They believe vehicle aging leads to deterioration and that deterioration makes older vehicles, compared with new ones, more prone to crashes and more susceptible to damages when crashes occur. As a result of both, they argue, older vehicles contribute disproportionately to highway losses.

Since the recommendations of the above report will influence highway safety countermeasures, it is important that the underlying hypotheses be carefully investigated. At the time this study was begun (more than a year before the Secretary's report was released), this question was asked: Are measurable crash phenomena associated with aging, and, if so, how may these be influenced by countermeasures such as motor vehicle inspection? Since past studies did not adequately examine the questions, this project was designed to investigate certain relevant factors in more detail.

THE EXPERIMENTAL PLAN

Two basic questions have been asked in this project. First, is the *severity* of a given crash a function of vehicle age? Second, is the *probability* of crash (of given severity) a function of vehicle age? (The statistical treatment of these questions is described elsewhere in this report.)

Simple analyses seem to show a positive correlation between increasing crash rates and increasing vehicle age. Schreiber and Schechter (1962) produced data (from their own study and two earlier ones) first indicating that the number of crashes per mile travelled increases as vehicle age increases. However, when they subjected their data to further

*This study was sponsored by The University of Michigan Highway Safety Research Institute. However, the conclusions are those of the authors and should not be interpreted as representing the views of either the University or the Institute.

analysis this positive correlation was shown to be an artifact of their analytical method, and a final analysis indicated no discernible correlation between the two variables. (It should be noted that their study involved a fleet of cars in which the miles actually travelled by individual vehicles were measurable.)

The approach taken here differs from earlier studies primarily in the more detailed classification of crashes and in the techniques used for developing sample and control populations. In the sample populations obtained for earlier studies, crashes were treated as a single criterion without regard to severity. To determine whether certain aging–crash characteristics might have been masked by this broad treatment, the crashes in the present study were categorized according to severity: fatal crashes, severe personal injury crashes, and minor crashes. (The classification procedures are described in a later section.)

The problem of controlling for exposure to crash-producing situations always creates uncertainties in studies of this type. Earlier investigators have used "miles travelled" as the relevant parameter. However, Schreiber and Schechter point out that the risk of crashes also varies markedly as a function of driving conditions.

In this study, exposure has been controlled simply by assuming that the crash risk for vehicles of a given age is directly related to the proportion of the total vehicle population represented by the number of vehicles of that age. This eliminates the necessity of obtaining mileage data (an important advantage, since obtaining reliable mileage data for vehicles in the general population is difficult).

SAMPLING METHODOLOGY

Choosing the overall vehicle-age distributions as the control parameter raises the difficult problem of insuring that the crash-vehicle sample is drawn from the same population as is the control sample. Despite their large numbers when integrated over time and space, the number of crashes occurring within a given time period and within a given geographic area is small. Similarly, vehicle-age distribution is a function of both time and space. For example, a vehicle involved in a crash in Detroit, Michigan, in January is almost certain to have come from a significantly different vehicle population than a vehicle involved in a crash in Traverse City, Michigan, in August.

In order to control this problem, crash data were drawn from limited geographic areas during a given fixed time period. Three Michigan counties, Washtenaw, Kalamazoo, and Muskegon, were selected as the area laboratories to test the geographic extent of any patterns which might emerge. Washtenaw County, the home county of The Highway Safety Research Institute, where the research was conducted, offers a mix of rural and town driving, with a single large-town complex (Ann Arbor – Ypsilanti) embedded in an otherwise rural small-town county. The county is crossed east to west (I-94 and U.S. 12) and north to south (U.S. 23) by major traffic arteries. Kalamazoo and Muskegon Counties were selected because their geographical and population characteristics seem to match those of Washtenaw County adequately; both counties are predominantly rural, each containing a single large town (Kalamazoo and Muskegon, respectively). Kalamazoo County is crossed east to west (I-94) and north to south (U.S. 31) by major arteries, and Muskegon County is crossed north to south by a major artery (U.S.-31) and is the western terminus of another (I-96).*

* Of these traffic arteries, I-94, which is a major link between Detroit and Chicago, is probably the most heavily travelled. I-96, linking Detroit, Lansing, and Grand Rapids, probably stands second. U.S.-23, being part of the major north–south artery in Michigan, carries much holiday traffic and is a link between the industrial complex around Saginaw and Bay City and lower south-east Michigan. However, the most heavily travelled portions of U.S.-23 are probably north of Washtenaw County.

For comparison, the relevant populations from each of the counties and their major cities are shown in Table 1.

TABLE 1. POPULATION DATA 1966

County	Population*	No. of vehicles†	Major city	Population
Kalamazoo	169,712	77,321	Kalamazoo	82,089
Muskegon	149,943	63,884	Muskegon	46,485
Washtenaw	172,440	80,662	Ann Arbor	67,340

The period between January 1, 1966 and September 30, 1966, was selected as the study time frame. (The September 30 cut-off eliminated 1967 vehicles introduced about October 1, 1966.)

During the study time frame, legally reportable crashes were those "in which any person is killed or injured or in which damage in excess of $100.00 is done to the property of any one person . . ."‡ Police officers investigate and report all eligible crashes called to their attention, and original copies of the reports are maintained in the Michigan State Police central record files located in East Lansing, Michigan. The reports are filed chronologically by county, allowing for straightforward procedures in sampling from the relevant crash populations.

This study is limited strictly to four-wheeled passenger automobiles (trucks, buses, and cycles are excluded, as are automobiles involved in accidents with pedestrians). The only parameters of concern are model year (the vehicle age parameter) and crash severity.

Obtaining control samples describing (in terms of vehicle age distributions) the populations from which the crash samples were drawn is difficult, since the parent vehicle populations were continually changing in make-up throughout the study time frame. Consequently, the distribution representing the aggregate population cannot be measured at an instant in time, but instead must be derived. Accordingly, procedures were developed for deriving such distributions from published passenger car registration records. These procedures and the problems encountered are vital to the validity of this work: they are described in Appendix A.

THE DATA

Devising a crash-severity classification scheme for this study was aided materially by the uniform accident reporting form in use throughout Michigan. Officers investigating accidents estimate and record the extent of injuries sustained by every occupant of each vehicle involved in a crash. Injuries are reported according to five discrete severity levels ranging from fatal injury to no injury. Although police officers gain expertise in evaluating injuries, neither their training nor their working conditions make for accurate medical judgments. What may appear to be a serious injury at the accident scene may prove to be minor and vice versa. However, the end points to the injury spectrum—fatal injury and no injury—are relatively objective. (When deaths occur after removal from the scene, the

* Data Source: 1967 edition Michigan Official Highway Map (1960 census or later).

† Original registrations of 1966 series license plates (valid 11/1/65 through 10/31/66). Data source: Michigan Department of State.

‡ See Michigan Vehicle Code (Revision of 1965), Section 200. Minimum reportable property damage has since increased to $200.

on-the-spot report is changed accordingly.) To reduce evaluation errors and to increase the sizes of the samples in each category the data were re-cast into only three severity classes:

Class A: Fatal injury crashes. These are hereafter referred to as fatal crashes.
Class B: Severe personal injury crashes. These are hereafter referred to as severe crashes.
Class C: Minor personal injury or only property damage crashes. These are hereafter referred to as minor crashes.

Injuries, of course, occur only to people and not to the vehicles themselves, except in terms of property damage. Therefore, the following measure was developed for associating vehicles with crash severity: each vehicle was assigned severity class A, B, or C according to the most severe injury sustained by any occupant of the vehicle. To illustrate: if a three-car crash produced one person killed in one vehicle, one person injured seriously in the second, and only property damage to the third, then the three vehicles would receive severity classifications A, B, and C, respectively. (In an alternative scheme, every vehicle was classified according to the most severe injury to any occupant of any car in the crash. Since analyses of the data grouped in that fashion suggest no different inferences, they have been omitted from this report.)

All fatal crashes occurring within the study time frame and about ten per cent of all reported non-fatal crashes are included in the study. Because non-fatal accident reports are filed chronologically by township in each county, the following sampling technique was used. The first record in each township and every tenth record thereafter were sampled, and if fewer than 10 records remained in a file after the last examined, no more were selected from it. The procedure was designed to produce a sample of slightly more than ten per cent of all non-fatal crashes.

Tables 2, 3, and 4 present data* from each of the three study counties, and Table 5 presents all the data together. The following data are included in each table:

TABLE 2. KALAMAZOO COUNTY POPULATION SAMPLES

Model year	Crashes: Fatal	Crashes: Severe	Crashes: Minor	Control Population
1966	2	5	70	242
1965	3	5	108	485
1964	4	7	97	388
1963	2	5	106	338
1962	1	8	74	307
1961	2	5	62	249
1960	4	9	67	272
1959	0	4	46	207
1958	2	12	77	421
Total	20	60	707	2909

* Unfortunately, crash vehicles were not categorized by county of registration. This means if out-of-county cars frequently came into the three counties to crash, then there may be some bias in the crash data. However, this is believed not to be a serious fault (although one that should be corrected in future work) in view of the findings of this report.

Table 3. Muskegon county population samples

Model year	Crashes: Fatal	Crashes: Severe	Crashes: Minor	Control population
1966	0	3	59	194
1965	1	4	86	306
1964	1	4	61	294
1963	3	3	75	298
1962	0	5	70	283
1961	4	7	68	220
1960	2	5	56	253
1959	2	4	37	185
1958	3	9	97	394
Total	17	44	609	2427

Table 4. Washtenaw county population samples

Model Year	Crashes: Fatal	Crashes: Severe	Crashes: Minor	Control population
1966	7	10	56	336
1965	9	9	76	658
1964	7	11	67	525
1963	4	11	37	423
1962	1	8	32	342
1961	1	5	28	241
1960	3	3	37	256
1959	2	3	21	184
1958	1	9	28	391
Total	35	69	382	3356

Table 5. 3-Counties population samples

Model year	Crashes: Fatal	Crashes: Severe	Crashes: Minor	Control population
1966	10	18	185	772
1965	13	18	270	1449
1964	12	22	225	1207
1963	9	19	218	1059
1962	2	21	176	932
1961	7	18	158	710
1960	9	17	160	781
1959	4	11	104	576
1958	6	30	202	1206
Total	72	174	1698	8692

Column 1: The model year of the crash vehicles. (Data from each year are listed individually from 1959 through 1966. Vehicles of 1958 vintage or older are listed together as 58 + .)

Column 2: The age distribution of fatal crash vehicles. (The complete population generated during the study time frame.)

Column 3: The age distribution of severe crash vehicles. (Slightly greater than a 10 per cent sample.)

Column 4: The age distribution of minor crash vehicles. (Slightly greater than a 10 per cent sample.)

Column 5: The age distribution of the vehicle population which produced the crash vehicles. (Slightly less than a 4 per cent sample: see Appendix A.)

Statistical tests have been made (the results are contained in the next section) showing that no distribution of crashed vehicles in the four data sets is statistically different from the parent population from which it was drawn. Although the most important inferences are to be drawn from this finding, some representative data plots may prove helpful to the reader. Accordingly, Figs. 1–3, representing fatal, severe, and minor injury populations respectively, are placed at this point in the report. Since no statistically different trends were detected among the data sets, the plots have been limited to the lumped data from the three counties.

Before these figures are discussed, the parameter plotted must be defined. The data in each sample are distributed by model year. The "involvement percentage" of any model year in any crash sample is computed as the quotient of the number of vehicles of that model year divided by the total number of vehicles in the crash sample: the "control percentage" of any model year in a control vehicle population may be computed similarly. (Thus, if there were ten 1966 model cars in fatal crashes and a total of 100 cars of all model years in fatal crashes, then the 1966 model involvement percentage in fatal crashes would

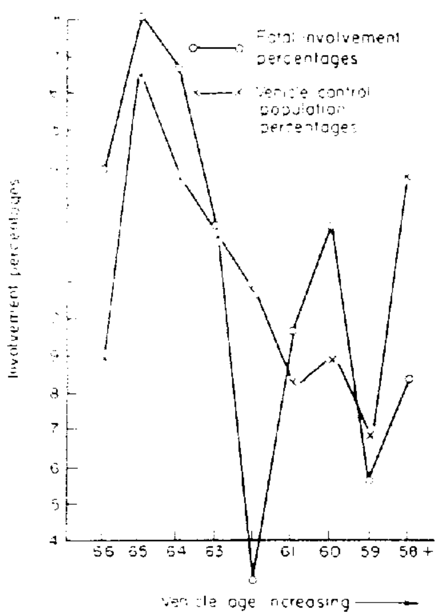

FIG. 1. Fatal crashes—involvement percentages (3 counties data).

FIG. 2. Severe crashes involvement percentages (3 counties data).

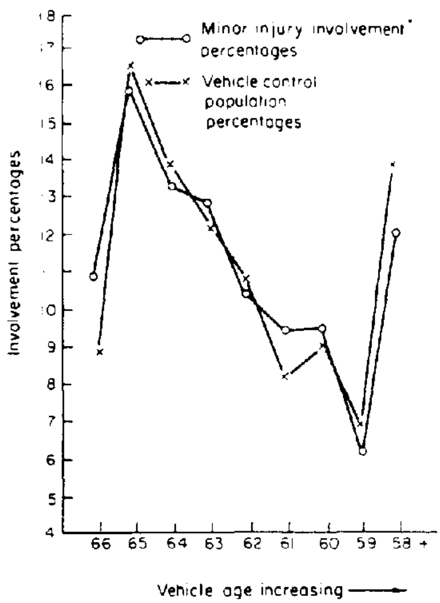

FIG. 3. Minor crashes involvement percentages (3 counties data).

be 10 per cent.) Having generated such percentages, one can compare the trend of crash involvement with the control populations by reference to Figs. 1, 2 and 3 which plot involvement percentages and control percentages together (fatal crashes, severe crashes and minor crashes, respectively). Figure 4 shows the involvement percentages for all three severity classes plotted together. (Table 6 contains the data plotted in Figs. 1–4.)

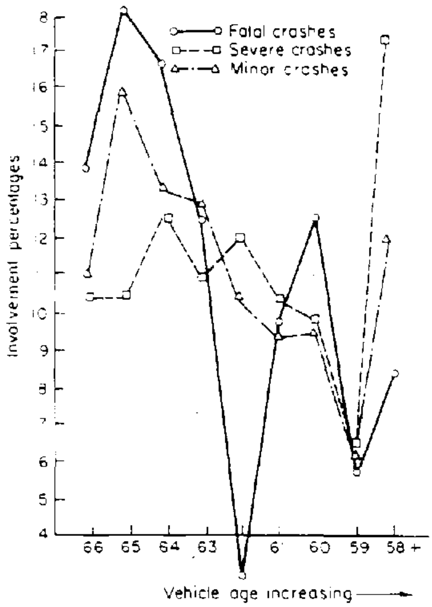

FIG. 4. Comparison of involvement percentages (3 counties data).

For any age (model year) in which the crash involvement percentage exceeds the control percentage, vehicles of that age are over-represented in the crash population. Likewise, vehicles of a given age are under-represented in the crash population when the control percentage exceeds the crash involvement percentage. (One could divide the two percentages to produce an "over-representation" ratio: however, since the crash populations are not statistically different from the control populations, such ratios might be misleading in these cases.)

Two observations about these figures are worth making. One is that the involvement percentages of fatal and severe crashes are much less stable with respect to the parent population than are the minor crashes. This greater stability for the minor crashes is probably a product of the larger samples. The second is that the crash involvement percentages (particularly for the minor crashes) trace the parent population with remarkable precision.

DATA ANALYSES

TABLE 6. INVOLVEMENT PERCENTAGE DATA FOR FIGURES 1–4 (3 COUNTIES)

Model year	Involvement percentages			
	Fatal	Severe	Minor	Control population
1966	13·89	10·34	10·89	8·83
1965	18·06	10·34	15·90	16·56
1964	16·67	12·64	13·25	13·82
1963	12·50	10·92	12·84	12·15
1962	2·78	12·07	10·36	10·71
1961	9·72	10·34	9·31	8·18
1960	12·50	9·77	9·42	9·01
1959	5·56	6·32	6·12	6·65
1958 +	8·33	17·24	11·90	13·92

The analyses were designed to detect aging phenomena associated with vehicles involved in crashes. Two suspected phenomena were: (1) given that crashes occur to vehicles of all ages, the population of vehicles involved in more serious crashes is likely to differ in age characteristics; and, (2) the age distribution of the crash population is likely to differ from the age distribution of the parent population from which it is drawn.

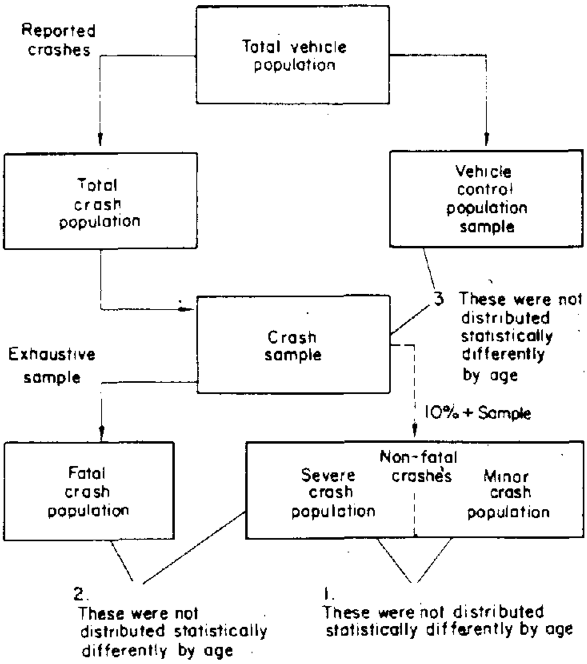

FIG. 5. Sampling and analytical schemes.

The analytical scheme followed may be explained easily by reference to Fig. 5. (The data from each of three counties and the lumped data have been organized separately and analyzed as described here.) The populations of the three crash samples (fatal, severe, and minor) were tested to determine whether they are distributed differently with respect to age. (For reasons to be explained, first the two non-fatal populations were compared; then they were lumped and compared with the fatals.) Next, it was planned to compare each crash population with the sample drawn from the total vehicle population to test for differences in the age-distributions. However, as we shall see, because the crash samples did not differ, it was only necessary to compare the non-fatal crash population to the control population sample.

Had aging phenomena been detected, over-representation ratios would have been computed and used to show how the phenomena vary with age. Even though the results of the analyses showed that over-representation ratios from these data are not statistically different from one, the concept is important and has been retained in the following discussions.

ASSOCIATION OF CRASH SEVERITY AND VEHICLE AGE

The basic question under investigation in this section is: given that an accident has occurred, is there any detectable association between vehicle age and severity of injury sustained by the occupants?

Let us denote the probability that vehicles of age i (A_i) are involved in crashes of severity j (S_j) by $\Pr\{A_i, S_j \mid \text{Crash}\}$. If age and severity are independent, this probability can be written as $\Pr\{S_j \mid \text{Crash}\} \cdot \Pr\{A_i \mid \text{Crash}\}$. That is, the joint probability of severity and age is equal to the product of the marginal probabilities of these factors. The crash samples will be used to test the hypothesis of independence between age and severity.

Crash-involved vehicles are classified by vehicle age and severity of the most severe injury suffered in the vehicle. Vehicle age has been estimated by the model year of the vehicle and severity has been assigned from one of the three classifications: fatal crashes, severe crashes, or minor crashes.

The non-fatal crash data were collected by taking a ten per cent stratified systematic sample from the three counties. Bivariate frequency tables for vehicle age versus crash severity have been presented in Table 7.

The χ^2 test, documented in statistical texts such as Hogg and Craig (1965), is commonly used to test for association in such contingency tables, and it has been used here to test the null hypothesis of independence between the minor crash distributions and the severe crash distributions shown in these Tables. In all cases, the attained χ^2 statistic was less than that required for rejection of the null hypothesis at a 0·05 level of significance. (All cases in this study had 8 degrees of freedom, requiring $\chi^2 > 15{\cdot}5$ for significance at the 0·05 level.) This leads one to infer that once a non-fatal crash occurs, the severity does not vary significantly with the age of the vehicles in the populations.

Fatal crash data were collected by exhaustively sampling fatal accidents occurring during the sample time frame in all three counties. Although strictly speaking these data are not samples inasmuch as all the cases in a county are included, they have been treated as random samples from some larger geographical region and or longer time frame. It was then asked whether the age distribution of fatal crash vehicles is different from the age distribution of non-fatal crash vehicles. Again, χ^2 tests have been used to test the hypothesis that these multinominal distributions are not different. The samples and resulting χ^2 statistics are presented in Table 8.

TABLE 7. COMPARISON OF MINOR AND SEVERE CRASH AGE-DISTRIBUTIONS

	(a) Muskegon		(b) Kalamazoo		(c) Washtenaw		(d) 3-Counties	
Model year	Severe crashes number	Minor crashes number	Severe crashes number	Minor crashes number	Severe crashes number	Minor crashes number	Severe crashes number	Minor crashes number
1966	3	59	5	70	10	56	18	185
1965	4	86	5	108	9	76	18	270
1964	4	61	7	97	11	67	22	225
1963	3	75	5	106	11	37	19	218
1962	5	70	8	74	8	32	21	176
1961	7	68	5	62	5	28	18	158
1960	5	56	9	67	3	37	17	160
1959	4	37	4	46	3	21	11	104
1958	9	97	12	77	9	28	30	202
	χ^2 4·31		χ^2 9·91		χ^2 8·72		χ^2 8·00	

TABLE 8. COMPARISON OF FATAL AND NON-FATAL CRASH AGE-DISTRIBUTIONS

Model year	(a) Muskegon		(b) Kalamazoo		(c) Washtenaw		(d) 3-Counties	
	Fatal crashes number	Non-fatal crashes number	Fatal crashes number	Non-fatal crashes number	Fatal crashes number	Non-fatal crashes number	Fatal crashes number	Non-fatal crashes number
1966	0	62	2	75	7	66	10	203
1965	1	90	3	113	9	85	13	288
1964	1	65	4	104	7	78	12	247
1963	3	78	2	111	4	48	9	237
1962	0	75	1	82	1	40	2	197
1961	4	75	2	67	1	33	7	176
1960	2	61	4	76	3	40	9	177
1959	2	41	0	50	2	24	4	115
1958 –	3	106	2	89	1	37	6	232
	$\chi^2 = 8{\cdot}40$		$\chi^2 = 4{\cdot}80$		$\chi^2 = 5{\cdot}08$		$\chi^2 = 7{\cdot}25$	

In all cases the data fail to yield χ^2 statistics large enough to reject the hypothesis of no difference in the underlying populations. That is, the data show no significant differences between the age distributions of vehicles in the fatal and in the non-fatal crash vehicle populations.

In summary, no significant statistical differences have been found among the age distributions of crashed vehicles, classified according to crash severity. The implications of this will be discussed in another section.

ASSOCIATION OF CRASH OCCURRENCE AND VEHICLE AGE

In studying the association of crash frequency with any parameter (in this case vehicle age) one attempts to estimate the probability of a crash given a particular value of that parameter. Hence, in this study $\Pr\{\text{Crash}|A_i\}$ is estimated using Bayes' Theorem expressed as:

$$\Pr\{\text{Crash}|A_i\} = \frac{\Pr\{A_i|\text{Crash}\}\times\Pr\{\text{Crash}\}}{\Pr\{A_i|\text{Crash}\}\times\Pr\{\text{Crash}\}+\Pr\{A_i|\text{No Crash}\}\times\Pr\{\text{No Crash}\}}.$$

A more useful form of this expression may be obtained by transforming these probabilities to odds, where the odds in favor of any event A are: $\Pr(A)/[1-\Pr(A)]$. After some manipulation, the above expression becomes:

$$\text{Odds}\{\text{Crash}|A_i\} = \frac{\Pr\{A_i|\text{Crash}\}}{\Pr\{A_i|\text{No Crash}\}}\times\text{Odds}\{\text{Crash}\}.$$

Thus, the odds in favor of a crash, given vehicle age i, are equal to the "likelihood ratio" of vehicle age in the crash and non-crash populations times the prior unconditional odds in favor of an accident. This is a most useful representation, for the "likelihood ratio" (or "over-representation ratio") is exactly the "weight" by which knowledge of vehicle age increases our estimate of the probability (odds) of a crash.

Hence, an over-representation ratio greater than 1 for a given vehicle age indicates that the odds in favor of a crash are increased. A ratio equal to 1 indicates no change.

Since only a sample from the crash and non-crash populations (the control sample described earlier) is available, over-representation ratios can only be estimated from our data. Therefore, before attaching meaning to them, the data should be tested to determine whether these crash populations and control populations are in fact different.

Since the data come from multinomial populations, the χ^2 test has again been used to test whether the two populations are the same. The samples and resulting χ^2 statistics are presented in Table 9. As before, the attained χ^2 statistics reveal no significant differences at the 0·05 level of significance.* That is, no evidence has been found to reject the hypothesis that the true over-representation ratios are equal to 1.

TABLE 9. COMPARISON OF NON-FATAL CRASHES (SEVERE AND MINOR) TO CONTROL SAMPLE AGE DISTRIBUTIONS

	(a) Muskegon		(b) Kalamazoo		(c) Washtenaw		(d) 3-Counties	
Model year	Non-fatal number	Control number	Non-fatal number	Control number	Non-fatal number	Control number	Non-fatal number	Control number
1966	62	194	75	242	66	336	203	772
1965	90	306	113	485	85	658	288	1449
1964	65	294	104	388	78	525	247	1207
1963	78	298	111	338	48	423	237	1059
1962	75	283	82	307	40	342	197	932
1961	75	220	67	249	33	241	176	710
1960	61	254	76	272	40	256	177	781
1959	41	185	50	207	24	184	115	576
1958	106	394	89	421	37	391	232	1206
	χ^2 9·12		χ^2 13·11		χ^2 15·79		χ^2 15·06	

LIMITATIONS IN DATA AND ANALYSIS

The data are limited geographically to three counties and in time to nine months; consequently, it may not represent a random sample with respect to some larger geographical and/or time population. However, no unusual disturbing variables affecting the sample obtained are suspected, so inferences might reasonably be extended to some larger population. Nevertheless, a larger sample would be desirable in validating or rejecting the results of these analyses.

In addition, although the χ^2 tests which have been applied to the data hold strictly for asymptotic (very large) samples, practical historical experience documented by Grizzle (1967) and others suggests them to be applicable when all expected counts reach five or more. In several places in this study, counts smaller than five were obtained, especially in the fatal crash populations. Hence, a larger random sample would enhance the validity of χ^2 tests.

* The Washtenaw County Population differences alone are just significant at the 0·05 level. However, since there is no obvious trend in the "over-representation" ratio for this county and since the pooled data reflect no significant differences, we have chosen not to analyze this further.

DISCUSSION

With respect to the data samples included in this study, the important findings are:

(1) The populations of passenger automobiles involved in crashes (of whatever severity) and the parent vehicle populations from which they are selected are not distributed statistically differently with respect to vehicle ages. (This finding held for the samples from each of the three counties, and for the lumped data treated as a single sample.)*

(2) When crashes involving passenger automobiles are classified according to crash severity, the populations involved in fatal crashes, severe crashes, and minor crashes are not distributed statistically differently with respect to vehicle ages. (This finding held for the samples from each of the three counties and for the lumped data treated as a single sample.)

If the findings had been different—if, for example, older vehicles had been over-represented in crashes with respect to the total vehicle population—then an inference that aging somehow makes crashes more likely (intuitively, through deterioration) would have been justified. From that, one might have argued in support of a program for inspecting vehicles to ensure continued mechanical soundness. These data do not support such conclusions, and, although the data do not allow one to conclude that inspecting vehicles cannot influence the potential occurrence of crashes, the findings do suggest (to the authors at least) that different phenomena should be investigated before expending resources on inspecting vehicles in hope of reducing crash and death rates.

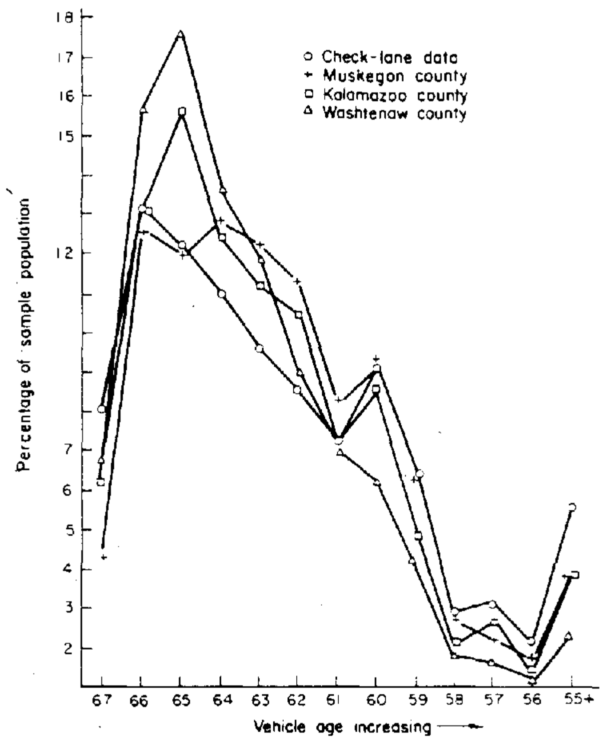

FIG. 6. Comparative vehicle population data (1967 samples).

* With the exception of the one case mentioned in the footnote on page 46.

On the other hand, the data do tend to expose as myth the notion that "old clunkers" are to blame for a great many highway deaths. If anything, new vehicles may be over-represented in crash populations—particularly fatal crash populations. (Refer to Figs. 1–3. However, one must bear in mind that the trends do not "prove" over-representation, since the crash populations and the parent populations are not statistically different.) A confirmation of this hypothesis would further discount recent studies, Buxbaum and Colton (1966), Colton and Buxbaum (1968), and Fuchs and Leveson (1967), favoring vehicle inspections, because those studies used motor vehicle death rates as the relevant criteria. Indeed, an over-representation of newer vehicles in fatal crashes would suggest the existence of causative factors not likely to be detected by inspecting vehicles for operating defects. (These same data are being analyzed using other characteristics as relevant parameters in an effort to determine whether other factors appear to be involved.)

The objections might be raised that older cars would not appear to be over-represented in crash populations because they are driven fewer miles per unit time. Certainly, if the registered older cars spend more time parked than do the newer ones, they would be less exposed to traffic hazards. The only data available for this study suggest this is not the case. Refer to Fig. 6 showing plots of four vehicle populations: the age distributions (by model year) of the samples from the 1967 registered vehicle populations for each of the three counties in the study; and the age distribution (by model year) of the vehicle sample (32,916 vehicles) obtained by the Michigan State Police in their check-lane inspections at multiple locations throughout the State between mid-March 1967 and June 30, 1967. (A strict following of the check-lane rules should have produced a random sample drawn from the vehicles passing the inspection sites.*)

A comparison of the distribution of the check-lane sample with that of the registered vehicle populations suggests that the age distribution of the vehicle population exposed to the check-lanes is about the same as that of the total population, but with slightly more older cars. The same over-exposure may prevail with respect to the hazards which produce crashes, although that cannot be asserted without further evidence, since the state-wide distribution producing the check-lane data could differ from the samples from the three counties. Nevertheless, on the surface the data seem to refute any notion that newer cars are likely to be over-exposed to traffic hazards relative to their numbers than are older ones.

The second finding—given that crashes occur, the vehicles involved in the populations of fatal, severe, and minor crashes are not distributed statistically differently with respect to age—fails to support any notion that crashworthiness (resistance to damage once a crash occurs) deteriorates with age. By the same reasoning, it also fails to support an argument that vehicle design and manufacturing advances have enhanced crashworthiness (up through the 1966 model cars). If the data had showed older vehicles to be more strongly associated with fatal and severe crashes than with minor crashes (and, perforce, the converse for newer cars), then one would have had some evidence for promoting special

* The data gathered during the first month (March–April 1967) in which check-lane inspections were made in Michigan contained slightly more newer cars than indicated by the six-month totals. Conversely, the later samples, as well as the six-month accumulation, showed more older cars than in the beginning. Discussions with a few check-lane operators suggest that they have learned to discriminate against older cars in choosing cars for inspection from the traffic stream. Furthermore, the institution of the check-lane program particularly during its opening weeks, brought a number of "volunteers" who as a rule drove newer vehicles. Consequently, newer cars may have been over-represented in the early check-lane samples and older ones over-represented in later samples, each based on the traffic streams being sampled.

programs aimed at maintaining crashworthiness as vehicles age in hope of reducing the severity of the crashes that occur. The data do not provide evidence supporting such an approach.

Had statistically significant differences been found among the various populations, over-representation ratios (defined in the preceding section) would have been computed to obtain a mathematical index of safety for vehicles of each model year. Although these findings do not justify using such an index here, the over-representation ratio concept should be useful in evaluating safety features which are added to new vehicles. For example, suppose a new crash prevention safety feature and a new damage minimization feature are added to automobiles as of model year 1970. Then, if the features are successful, the crash experience of the population of cars equipped with them should differ from that of the population of cars not so equipped in the following ways:

1. If the safety features do inhibit the occurrence of crashes, then cars so equipped should exhibit lower crash involvement in the year of introduction than was exhibited by new cars introduced without the features in earlier years. To illustrate, suppose new 1969 vehicles compile an over-representation ratio greater than one during their first year in the population, and suppose the 1970 models incorporate a new crash inhibiting feature. If this feature is effective, the over-representation ratio for the 1970 models during their first year should be less than that compiled by the 1969 models during their first year.

2. If the features minimize injury upon occurrence of a crash, then of the cars so equipped involved in crashes, the proportion of serious injuries to number of crashes should be smaller than was experienced by new cars introduced without the features in earlier years.

In addition to any reduction in the number of crashes (or number per unit of exposure), over-representation ratios should be lower for new, safer cars than these ratios were for earlier (but not so safe) cars when they were new. However, since new vehicle safety standards are being implemented along with renewed emphasis on a safer highway environment, changes in over-representation ratios, when they occur, may not be discretely assignable to any one particular countermeasure. Furthermore, such procedures may be valid for evaluating countermeasures only for a few years. If new safety features were to be introduced over one or two years, and if no additional features followed for a time, after several years the entire vehicle population would be similarly equipped and in later years the safety features themselves would not affect the crash performance of new models as compared with the new models of earlier years.

AFTERWORD

In conducting the study and writing this report, the researchers have attempted to remove any biases that might lead to unjustified inferences. However, several experimental factors might affect the weight a reader would wish to assign to the conclusions. All but one have been pointed out in text, but they are listed here, so that they may be considered together.

1. The number of fatal crashes (and, in individual counties, the number of severe crashes) was sometimes smaller than would be required to establish complete confidence in the results of the statistical tests imposed.

2. Automobiles not registered in the study county in which they crashed were not removed from the crash populations.

3. The derivation of truly representative control populations is difficult, and no independent check of the quality of those produced is currently available.

4. The data include only crashes reported to the police. Excluded were many crashes in which no injuries were suffered and in which property damage to any one car was less than $100. Moreover, authorities believe that a fair percentage of reportable accidents are not, in fact, reported. However, they also believe that virtually all fatal and serious personal injury accidents are reported.

The authors believe that none of these factors seriously impair the validity of the basic findings. Nevertheless, if they are thought to be significant with respect to the development of safety programs, then the authors recommend that the study be repeated using larger samples and eliminating, to the extent practicable, the deficiencies mentioned above.

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APPENDIX A. CONTROL POPULATIONS

Driving adjusted control distributions

The age distribution of the registered passenger vehicles in each county serves as the control parameter for this study. On the surface this choice is not the most desirable. However, data are available to produce this control, whereas data for alternative controls are not.

Even though the age distribution of registered vehicles is easy to conceive of, obtaining a single measurement representing a changing population over a nine-month time period is difficult. Some of the problems may be explained with reference to Fig. A–1, which presents Washtenaw County data. (Similar figures were constructed from Kalamazoo County and Muskegon County.) The ordinate represents the control percentage of any given model year in the total sample population from which it was chosen, and the abscissa represents time in months and years. Dates of events significant to this work are presented chronologically by vertical lines as follows:

1. On about October 1 of a given year, new model year cars are introduced. The percentage of these cars in the population starts growing from zero at about this date.

2. The vehicle registration year begins with November 1 of one calendar year and ends October 31 of the next. Vehicles registered between November 1 and December 31 appear in the registration files bearing the date of the next calendar year.

3. January 1 marks the beginning of the period during which crashes represented in this study occurred.

4. The last day of February is the day on which registrations under the preceding year become invalid, and all operating vehicles must have current registrations by this date.

5. All the original registrations accumulated between November 1 of the preceding calendar year and about May 15 (the exact date is not clear from the records) of the current

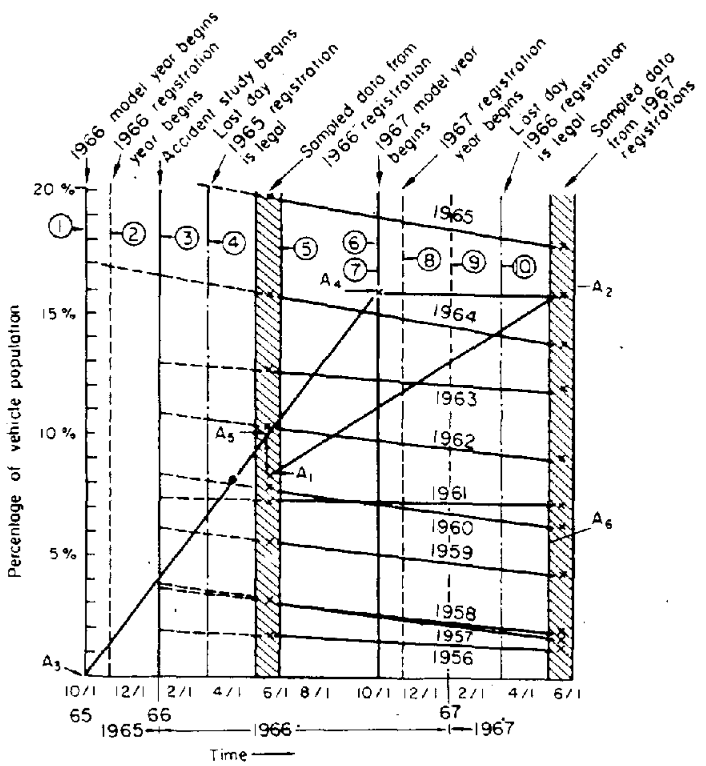


Fig. A-1. Age-distribution adjustment diagram.

calendar year are published about June 1. (Later registrations are filed but not published.) The shaded areas on Fig. A–1 between 5/1 and 6/1 represent the publication periods. The study population samples were drawn from the published data containing about ninety percent of the total number of original registrations for each county. Table A–1 confirms that observation and shows the registration accumulation rate in the three counties.

6. To avoid including 1967 models in the study populations the study period ended with crashes occurring on September 30, 1966.

7–8. Recurrence of events 1 and 2 in the succeeding year.

9–10. Recurrence of events 3 and 4 in the succeeding year.

Figure A–1 shows that the midpoint of the crash study period falls on May 15, which is about the time current year registrations are published. The published 1966 registrations are believed to understate 1966 model cars, because the publications contain only original registrations and many new cars, as they are purchased, are registered by transfer of current licenses from older cars. (In Michigan, registrations remain with the owner, not the vehicle, and when a car is traded for a different vehicle, the original registration is transferred to the second vehicle.) Therefore, it may be inferred that a number of 1966 model cars were registered by transfer* and were not represented in the published data. If so, the percentage of current model vehicles (1966) would be low. On the other hand, the

* Transfer registrations represent about 15 per cent of the total in Michigan. We do not know what proportion of the transfers are to new vehicles.

TABLE A–1. RATE OF REGISTRATION FOR PASSENGER CARS 1966 REGISTRATION YEAR

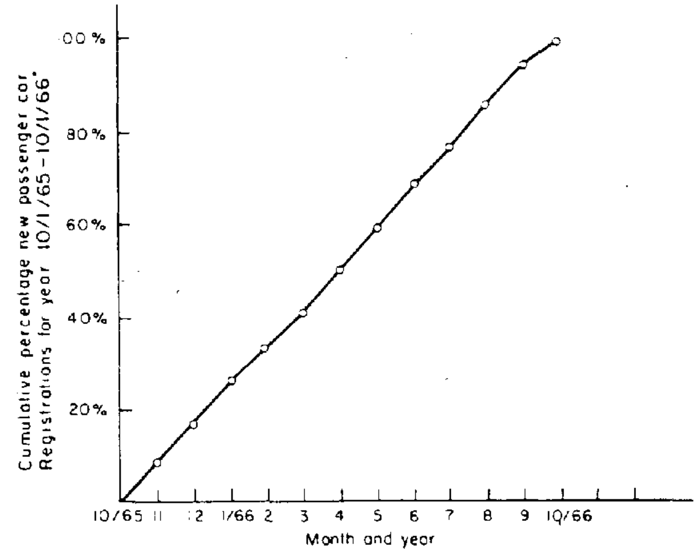
Model year	Kalamazoo County No.	Kalamazoo County Cumulative % of total	Muskegon County No.	Muskegon County Cumulative % of total	Washtenaw County No.	Washtenaw County Cumulative % of total
Nov. 1965	8166	10·56	6466	10·12	10036	12·44
Dec. 1965	6778	19·32	4551	17·24	6675	20·71
Jan. 1966	11352	34·00	8138	29·98	13771	37·38
Feb. 1966	28358	70·67	20877	62·66	24067	67·62
Mar. 1966	14251	89·10	16196	88·01	16182	87·68
Apr. 1966	1661	91·24	1601	90·52	1705	89·80
May 1966	1373	93·01	1329	92·60	1549	91·72
June 1966	1349	94·75	1173	94·43	1498	93·57
July 1966	1052	96·11	1046	96·07	1264	95·14
Aug. 1966	1121	97·55	924	97·52	1322	96·78
Sept. 1966	1144	99·02	891	98·91	1423	98·54
Oct. 1966	716	100·00	692	100·00	1130	100·00
	77321		63884		80622	

percentage of 1966 model vehicles taken from the 1967 publications should be close to the true figure because almost all the 1966 models would have been introduced before the 1967 registration year and few should have left the population during their first year. This is not entirely accurate, of course, but should be very close.

Table A–2 contains the samples drawn from the published registered vehicle populations and Table A–3 shows how large these samples are with respect to the populations from which they were drawn. The 1966 and 1967 sample data were adjusted to obtain the 1966 population age distributions which serve as the controls in this study. Table A–4 contains the adjusted distributions.

Adjustments were made as follows. First, a point (A_1 on Fig. A–1) was plotted on the vertical line through May 15, 1966, showing the control percentage of the 1966 cars in the total 1966 registration sample (data from Table A–2). Second, a point (A_2) was plotted at May 15, 1967, showing the control percentage of the 1966 cars in the total 1967 registration sample. Third, the two points were joined by a straight line representing uniform growth of the percentage of 1966 vehicles in the total control population. (Similar points were plotted and lines drawn for other model years down to 1956. All years—with two exceptions in the Muskegon data—showed a decline from 1966 to 1967. Although the other model year plots are shown on Fig. A–1, they are not necessary for the adjusting procedure.) Fourth, it was assumed that the 1966 model control percentage began at zero as of 1 October 1966 (Point A_3) and grew at a uniform rate to the control percentage of that model in the 1967-registration data, as of 1 October 1966 (Point A_4) when the 1967 models were introduced. Points A_3 and A_4 were joined by a straight line. (Although data from the study counties are not available to validate the uniform growth rate assumption, the national rate was uniform [Fig. A–2] and no local differences are suspected.) Fifth, the 1966 model control percentage in the adjusted 1966 distribution was obtained at the intersection (Point A_5) of the uniform growth rate line and the vertical line drawn through May 15, 1966. (The difference between A_5 and A_1 could be explained by the transferred registrations discussed earlier.)

Adjusting the 1966 model control percentage forced adjustments to each of the other



Mo Yr	No. (× 10^3)	%	Acc %
10/65	746	8·14	8·14
11/65	794	8·66	16·8
12/65	909	9·92	26·7
1/66	607	6·62	33·34
2/66	722	7·88	41·22
3/66	879	9·59	50·81
4/66	823	8·98	59·79
5/66	777	8·48	68·27
6/66	753	8·21	76·48
7/66	833	9·09	85·57
8/66	744	8·12	93·69
9/66	574	6·26	99·92

FIG. A-2. Rate of registering new passenger cars in the United States by month of year 10/1/65–10/1/66.

model year control percentages in order to retain a sum of 100 per cent. This was done as follows:

1. Subtract the 1966 model control percentage in the registration sample from the adjusted 1966 model control percentage (obtained as outlined above). (A_5–A_1 on Fig. A–1.)

2. Subtract the 1966 model control percentage in the 1966 registration sample from the 1966 model control percentage in the 1967 sample. (A_2–A_1 on Fig. A–1.)

3. Add to (2) the 1967 model percentage in the 1967 registration sample. (Point A_6 plotted on the vertical line through 5 May 1967.) This sum estimates the infusion of newly manufactured cars into the population between May 15, 1966, and May 15, 1967. Since the figures are percentages, the increase for new cars must be offset by an exit of older cars from the population.

4. The number computed in (1) was divided by the number from (3) to determine the portion of the adjustment that should be applied to the remaining model year control percentages from the 1966 registration sample. Each model year control percentage was

TABLE A 2. SAMPLE AGE-DISTRIBUTION FROM PUBLISHED PASSENGER CAR REGISTRATIONS 1966 AND 1967

Model year	Kalamazoo 1966 No. in sample	Kalamazoo 1966 %	Kalamazoo 1967 No. in sample	Kalamazoo 1967 %	Muskegon 1966 No. in sample	Muskegon 1966 %	Muskegon 1967 No. in sample	Muskegon 1967 %	Washtenaw 1966 No. in sample	Washtenaw 1966 %	Washtenaw 1967 No. in sample	Washtenaw 1967 %
1967			186	6·24			104	4·29			244	6·71
1966	143	5·03	392	13·15	119	4·88	307	12·69	253	8·20	580	15·97
1965	482	16·98	467	15·67	312	12·81	292	12·07	613	19·87	645	17·76
1964	386	13·60	370	12·41	289	11·86	311	12·85	491	15·92	495	13·63
1963	333	11·73	332	11·14	298	12·23	299	12·36	392	12·71	433	11·92
1962	300	10·57	313	10·50	284	11·66	277	11·45	319	10·34	327	9·00
1961	253	8·91	218	7·31	228	9·36	199	8·22	222	7·19	257	7·07
1960	272	9·58	255	8·55	264	10·84	222	9·17	241	7·81	230	6·33
1959	220	7·75	148	4·96	196	8·04	156	6·44	174	5·64	158	4·35
1958	449	15·82	299	10·01	445	18·27	252	10·41	379	12·28	262	7·21
Total	2838	99·97	2980	100·00	2435	99·95	2419	99·95	3084	99·96	3631	99·95

TABLE A-3. PASSENGER VEHICLE REGISTRATION AND SAMPLE INFORMATION 1966 SERIES

County	Total original registrations	Approximate number published	Sample drawn from published data	% Sample is of original registrations
Kalamazoo	77321	70992	2958	3·82%
Muskegon	63884	58440	2435	3·81%
Washtenaw	80622	73608	3067	3·80%

TABLE A-4. CONTROL DISTRIBUTIONS (ADJUSTED 1966 DATA)

Model year	Kalamazoo		Muskegon		Washtenaw		3-Counties*	
	Adjusted %	Computed number	Adjusted %	Computed number	Adjusted %	Computed number	Adjusted %	Computed number
1966	8·30	242	8·00	194	10·00	336	8·88	772
1965	16·68	485	12·62	306	19·61	658	16·67	1449
1964	13·33	388	12·11	294	15·64	525	13·88	1207
1963	11·60	338	12·26	298	12·62	423	12·18	1059
1962	10·56	307	11·66	283	10·18	342	10·72	932
1961	8·55	249	9·07	220	7·18	241	8·16	710
1960	9·35	272	10·41	253	7·63	256	8·98	781
1959	7·11	207	7·63	185	5·48	184	6·62	576
1958	14·48	421	16·22	394	11·64	391	13·87	1206
	99·96	2909	99·98	2427	99·98	3356	99·96	8692

* These numbers are generated by summing the computed frequencies over the three counties.

adjusted by first multiplying the ratio so obtained by the difference between the percentages (of each model year) as of 1966 and 1967, and then subtracting the product from the 1966 percentage.

Adjusted control percentages computed for each county are tabulated in Table A–4. From the products obtained and the averages of the number of data points in the 1966 and 1967 registration samples, adjusted frequency distributions by model year were calculated for each county and tabulated (Table A–4). These served as the control distributions. The three-counties distribution was obtained by summing over data from the three counties.

Sampling from the registered vehicle populations

The Michigan Department of State publishes passenger vehicle registrations in books by county (and letter prefix within a county) and each page contains a photograph of registration forms arranged in a matrix of six columns by eight rows. The first and last entry on each page was selected for the samples, making them just less than 4 per cent of the total populations. In cases of unreadable entries, the nearest readable one was taken. Model year was the only parameter extracted from the records.